

requiring centralized implementation. As γ increases, the off-diagonal elements of the feedback matrix become significantly sparser whereas the relative cost increases only slightly; see Figs. 3. Especially, for the L_q norm ($q=1/2$), when $r \geq 2$, the sparse process works in a low effect, while there is a persistent deterioration of the performance. For the performance analyze of the logarithmic norm, as γ increases, sparse structure and performance all have a bad discrimination. Compared with L_0 norm, the performance of L_1 norm has an increasing worsen due to its more sparse structure. Additionally, as γ increases, the performance of L_q norm shows a nearly linear power law changing, which is suitable for analyze and design of the control problem.

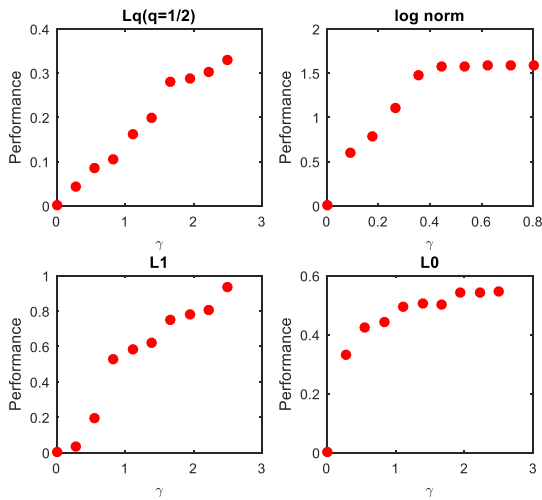


Figure 3. Performance for L_0 norm

6. CONCLUSIONS

In this paper, the effect of L_q ($0 < q < 1$) norm played as penalty function of an optimization scheme was presented. The optimization scheme uses the ADMM algorithm to minimize the steady-state variance of the sparse controlled system. The designed ADMM scheme consists two separating steps in which the penalty functions played as L_0 , L_1 and L_q regularized term. The simulation results showed that r has a nearly linear relationship with sparse structure and performance when at low value, and saturation effect appeared with the increasing of r . The results and analysis in this paper have potential applications to wide-area control in actual power systems.

ACKNOWLEDGMENT

We thank the support from the Jiangsu Province Science and Technology Innovation Training Program (NO. 201513989014Y).

REFERENCES

[1] G. Rogers, *Power System Oscillations*, Norwell, MA, USA: Kluwer, 2000. DOI: [10.1007/978-1-4615-4561-3](https://doi.org/10.1007/978-1-4615-4561-3).
 [2] K. Prasertwong, N. Mithulananthan, and D. Thakur, "Understanding low-frequency oscillation in power systems," *Int. J. Electr. Eng. Educ.*, vol. 47, pp. 248–262, 2010. DOI: [10.7227/IJEEE.47.3.2](https://doi.org/10.7227/IJEEE.47.3.2).

[3] F. Lin, M. Fardad, and M. R. Jovanović. "Design of optimal sparse feedback gains via the alternating direction method of multipliers". *IEEE Trans. Autom. Control*, vol. 58, no. 9, pp. 2426–2431, 2013. DOI: [10.1109/TAC.2013.2257618](https://doi.org/10.1109/TAC.2013.2257618).
 [4] C. Aranya and I. D. Marija, "Control and optimization methods for electric smart grids", Springer, 2012. DOI: [10.1007/978-1-4614-1605-0](https://doi.org/10.1007/978-1-4614-1605-0).
 [5] F. Dörfler, M. R. Jovanović, M. Chertkov, and F. Bullo, "Sparsity promoting optimal wide-area control of power networks," *IEEE Trans. Power Syst.*, pp. 2304465, 2014. DOI: [10.1109/ACC.2013.6580499](https://doi.org/10.1109/ACC.2013.6580499).
 [6] V. Venkatasubramanian and Y. Li, "Analysis of 1996 Western American electric blackouts," in *Bulk Power System Dynamics and Control-VI*, Cortina d'Ampezzo, Italy, 2004.
 [7] S. Arash, N. Sarmadi and V. Venkatasubramanian, "Inter-Area Resonance in Power SysteMS From Forced Oscillations," *IEEE Transaction on Power Systems*, vol. 31, pp. 378-386, 2016. DOI: [10.1109/TPWRS.2015.2400133](https://doi.org/10.1109/TPWRS.2015.2400133).
 [8] B. Chaudhuri and B. C. Pal, "Robust damping of multiple swing modes employing global stabilizing signals with a TCSC," *IEEE Trans. Power Syst.*, vol. 19, pp. 499–506, 2004. DOI: [10.1109/TPWRS.2003.821463](https://doi.org/10.1109/TPWRS.2003.821463).
 [9] C. Duan, W. L. Fang, and S. B. Niu, "Facts devices allocation via sparse optimization," *IEEE Transaction on Power Systems*, vol. 31, pp. 1308-1319, 2016. DOI: [10.1109/TPWRS.2015.2433891](https://doi.org/10.1109/TPWRS.2015.2433891).
 [10] M. Amin, "Special issue on energy infrastructure defense systems," *Proceedings of the IEEE*, vol. 93, no. 5, pp. 855–860, 2005. DOI: [10.1109/MILCOM.2006.302504](https://doi.org/10.1109/MILCOM.2006.302504).
 [11] A. Heniche and I. Karnwa, "Control loops selection to damp interarea oscillations of electrical networks," *IEEE Transactions on Power Systems*, vol. 17, no. 2, pp. 378–384, 2002. DOI: [10.1109/TPWRS.2002.1007907](https://doi.org/10.1109/TPWRS.2002.1007907).
 [12] L. P. Kunjumammed, R. Singh, and B. C. Pal, "Robust signal selection for damping of inter-area oscillations," *IET Generation, Transmission & Distribution*, vol. 6, no. 5, pp. 404–416, 2012. DOI: [10.1049/iet-gtd.2011.0670](https://doi.org/10.1049/iet-gtd.2011.0670).
 [13] Y. Zhang and A. Bose, "Design of wide-area damping controllers for interarea oscillations," *IEEE Transactions on Power Systems*, vol. 23, no. 3, pp. 1136–1143, 2008. DOI: [10.1109/TPWRS.2008.926718](https://doi.org/10.1109/TPWRS.2008.926718).
 [14] J. H. Chow and K. W. Cheung, "A toolbox for power system dynamics and control engineering education and research," *IEEE Transactions on Power Systems*, vol. 7, no. 4, pp. 1559–1564, 1992. DOI: [10.1109/59.207380](https://doi.org/10.1109/59.207380).
 [15] L. Rouco, "Eigenvalue-based methods for analysis and control of power system oscillations," in *Power System Dynamics Stabilisation*, IEE Colloquium on. IET, 1998. DOI: [10.1049/ic:19980031](https://doi.org/10.1049/ic:19980031).
 [16] P. Kundur, *Power system stability and control*, McGraw-Hill, 1994. DOI: [10.1109/9780470545577](https://doi.org/10.1109/9780470545577).
 [17] Z. Xu, X. Y. Chang, F. M. Xu and H. Zhang, " $L_{1/2}$ Regularization: A Threshold Representation Theory and a Fast Solver", *IEEE Trans on Neural Networks and Learning*, vol. 23, no. 7, pp. 1023-1027. DOI: [10.1109/TNNLS.2012.2197412](https://doi.org/10.1109/TNNLS.2012.2197412).